NASA Goddard Space Flight Center Laboratory for High Energy Astrophysics

Greenbelt, MD 20771

This report covers the period from July 1, 2003 to June 30, 2004.

This Laboratory's scientific research is directed toward experimental and theoretical investigations in the areas of X-ray, gamma-ray, gravitational wave and cosmic-ray astrophysics. The range of interests of the scientists includes the Sun and the solar system, stellar objects, binary systems, neutron stars, black holes, the interstellar medium, normal and active galaxies, galaxy clusters, cosmic ray particles, gravitational wave astrophysics, extragalactic background radiation, and cosmology. Scientists and engineers in the Laboratory also serve the scientific community, including project support such as acting as project scientists and providing technical assistance for various space missions. Also at any one time, there are typically between ten and fifteen graduate students involved in Ph.D. research work in this Laboratory.

1. PERSONNEL

Dr. Nicholas White is Chief of the Laboratory for High Energy Astrophysics. Dr. Neil Gehrels is Head of the Gamma Ray, Cosmic Ray, & Gravitational Wave Astrophysics Branch and Dr. Robert Petre is Head of the X-Ray Astrophysics Branch.

The civil service scientific staff includes: Drs. John Baker, Louis Barbier, Scott Barthelmy, Elihu Boldt, Kevin Boyce, Jordan Camp, Joan Centrella, Jean Cottam, Philip Deines-Jones, Enectali Figueroa-Feliciano, Keith Gendreau, Alice Harding, Robert Hartman, Stanley Hunter, Keith Jahoda, Frank Jones, Timothy Kallman, Demos Kazanas, Richard Kelley, Caroline Kilbourne, Marvin Leventhal (retired scientist), Francis Marshall, Stephen Merkowitz, John Mitchell, Israel Moya, Richard Mushotzky, Jay Norris, Ann Parsons, Bill Pence, Scott Porter, Donald Reames (Emeritus), Steve Ritz, Peter Selemtsos, Robin Stebbins, Floyd Stecker, Robert Streitmatter, Tod Strohmayer, Jean Swank, Bonnard Teegarden, David Thompson, Jack Tueller, Tycho von Rosenvinge, Kim Weaver and William Zhang.

The following scientists are National Research Council Associates: Drs. Peter Bloser, Jay Cummings, Jarek Dyks, Kenji Hamaguchi, Timothy Hamilton, Thomas Hams, Makoto Sasaki, Alex Markowitz, James Van Meter, Tarek Saab, Philip Uttley and Anna Watts.

The following researchers are University Space Research Association Scientists: Drs. Lorella Angelini, Zaven Arzoumanian, David Bertsch, Jerry Bonnell, Kai-Wing Chan, Dae-Il Choi, Robin Corbet, Mike Corcoran, Ken Ebisawa, Georgia de Nolfo, Steve Drake, Illana Harrus, Stephen Henderson, Stephen Holland, Stefan Immler, Hans Krimm, John Krizmanic, John Lehan, Volker Leonhordt, Jim Lochner, Alexander Moiseev, Koji Mukai, James Reeves, Chris Shrader, Steve Snowden, Yang Soong, Martin Still and Steve Sturner.

The following scientists are SP Systems Scientists: Drs. Analia Cillis and Thomas Cline

The following investigators are University of Maryland Scientists (including UMBC): Drs. Keith Arnaud, David Band, Simon Bandler, Volker Beckmann, Patricia Boyd, Gregory Brown, John Cannizzo, David Davis, Ian George, Masaharu Hirayama, Una Hwang, Yasushi Ikebe, Naoko Iyomoto, Kip Kuntz, Mark Lindeman, Mike Loewenstein, Craig Markwardt, Julie McEnery, Paul McNamara, Igor Moskalenko, Chee Ng, Patric Palmeri, Dirk Petry, Christopher Reynolds, Ian Richardson, Jane Turner and Ken Watanabe.

Visiting scientists from other institutions: Drs. Hilary Cane (Univ. of Tasmania), Fred Finkbeiner (SSAI), Ralph Fiorito (Catholic University), Hideyuki Fuke (KEK), Markos Georganopoulos (NRC), Kenji Numata (NRC), Takashi Okajima (JSPS), Randall Smith (JHU), Lev Titarchuk (NRL), Allan Tylka (NRL), Tahir Yaqoob (JHU) and Tetsuya Yoshida (KEK).

Other Support Scientists: Kevin Black (Forbin Scientific), Kazutami Misaki (JSPS), Robert Schaefer and Thomas Stephens (L3).

Graduate Students doing their thesis research in this Laboratory are: from the U. of Maryland, Wayne Baumgartner, David Fiske, Derek Hullinger, Breno Imbiriba, Barbara Mattson, Sean McWilliams, Luis Reyes, David Wren and Yuxuan Yang; from the University of Tokyo, Shinya Matsuda; from USRP, Reynaldo Castro; from George Washington Univeristy, Alla Ibrahim and from GSFC John Sadleir.

2. RESEARCH PROGRAMS

2.1 Sun and Solar Systems

Drs. Reames and Ng studied the abundances of heavy elements ($33 < Z < 83$) in solar energetic particles. Wave-particle interactions in solar flares cause large (_ 1000_ coronal) enhancements in these abundances in the accelerated particles, but no such enhancements are seen in particles accelerated at CME-driven shock waves. Dr. Reames published a review of the variations in solar energetic particle events, including the evidence over the last 400 years seen in ice cores.

Drs. Snowden and Kuntz with Dr. M. Collier (NASA/GSFC LEP) observed solar wind charge exchange X-ray emission using the XMM-Newton observatory. The mission likely originated from the sub-solar position of Earth's magnetosheath and consisted of emission lines of highly ionized oxygen, neon, magnesium, and probably carbon. The detection was serendipitous and the emission occurred during a strong flux enhancement of the solar wind. This result suggests the utility of using such observations to map the structure of the geosphere/solar wind interface region in relatively fine detail.

2.2 Stars

During the past year Dr. Corcoran has continued studying the X-ray emission from the supermassive star Eta Carinae.

In June 2003 Eta Carinae underwent an X-ray minimum, an event that recurs every 5.5 years. During this time Dr. Corcoran monitored the X-ray brightness of Eta Carinae on a daily basis using the Rossi X-ray Timing Explorer and communicated these results via a website he maintained to other ground- and space-based observers.

Drs. Hamaguchi and Corcoran are analyzing X-ray observations of Eta Car obtained with the XMM-Newton X-ray Observatory, and Dr. Corcoran is collaborating with Dr. J. Pittard (Leeds) and Mr. D. Henley (Birmingham) on analysis of X-ray grating data obtained through the X-ray minimum with the Chandra X-ray Observatory.

Drs. Corcoran, Hamaguchi, Gull (GSFC/LASP), Petre and Pittard along with Dr. K. Davidson (Minnesota), Dr. D. Hillier (Pittsburgh), Dr. N. Smith (Colorado), Dr. J. Morse (Arizona), Dr. A. Damineli (Sao Paolo), Dr. N. Walborn (STScI), Dr. E. Verner and Mr. N. Collins (Catholic U.), Dr. K. Weis and Dr. D. Bomans (Ruhr-University of Bochum) and Dr. Y. Butt (CfA) used a deep Chandra X-ray observation during the X-ray minimum to reveal for the first time X-ray emission from the Homunculus Nebula surrounding Eta Car.

2.3 Pulsars and Magnetars

Drs. A. Harding, A. Muslimov (Mantech Corp) and J. Dyks are developing a new model for particle acceleration and high-energy emission from rotation-powered pulsars. The slot gap model involves particle acceleration and high-energy emission from the polar cap up to very high altitudes in the pulsar magnetosphere. Radiation from the slot gap can produce profiles similar to those of observed gamma-ray pulsars. The combination of a small emission solid angle with a high probability of viewing the emission predicts that more gamma-ray pulsars should be detectable at large distances. In this picture, many of the EGRET unidentified sources are be a radio-loud gamma-ray pulsar.

Population synthesis studies of gamma ray and radio pulsars in the Galaxy are being carried out by Drs. A. Harding and P. Gonthier (Hope College). These studies are showing that polar cap/slot gap models predict that radio-loud pulsars significantly outnumber radio-quiet gamma-ray pulsars, in contrast with outer gap models, which predict vastly more radio-quiet pulsars. This provides GLAST with an excellent diagnostic with which to distinguish these different high-energy emission models.

Dr. Arzoumanian, with Drs. D. Champion, D. Lorimer, M. McLaughlin (all of U. Manchester), J. Weisberg (Carleton College), and J. Taylor (Princeton U.), reported the discovery of a new Galactic binary radio pulsar, J1829+2456, in a mid-latitude drift-scan survey with the Arecibo telescope. Initial timing observations showed the 41-ms pulsar to be in a 28-h, slightly eccentric, binary orbit. The advance of periastron was derived from timing observations spanning 200 days: assuming that it is due purely to relativistic gravity, and given a reasonable range of masses for the PSR J1829+2456 neutron star, the team constrained the companion mass to be between 1.22 and 1.38 Msolar, making it likely to be another neutron star. A firm upper limit on the pulsar mass of 1.38 Msolar was also derived. The expected coalescence time due to gravitational radiation is long ($\sim$60 Gyr), so that this system's discovery does not significantly affect calculations of merger rates relevant to upcoming gravitational-wave instruments such as LIGO, but its evolutionary history and potential for measurement of additional relativistic effects are being pursued.

Dr. Arzoumanian, with Drs. S. Safi-Harb (U. Manitoba), T. Landecker, and R. Kothes (NRC-HIA) reported the discovery, in archival ROSAT and ASCA observations, of X-ray emission from the direction of DA 495 (G65.7+1.2), a likely supernova remnant of uncertain classification but with similarities to the Crab Nebula. An unusual feature of the radio nebula is its annular morphology, with a flux minimum at the geometrical center. In the soft X-ray band, the ROSAT data revealed a compact source near the edge of the central radio ''hole''; the hard X-ray morphology, at the limit of ASCA's angular resolution, is suggestive of extended emission coincident with the ROSAT source. The X-ray flux was found to be roughly constant with time, and its spectrum well described by a power law with photon index $\sim$1.7. Taken together, this evidence suggests identification of the X-ray source with a magnetospherically active neutron star and its associated wind nebula. Timing analysis of the ASCA data yielded only a weak upper bound on pulsations with periods $>\sim$30 ms. These results revealed for the first time the high-energy engine that powers the DA 495 radio nebula, strengthening its classification as a plerionic supernova remnant, one that may represent the poorly explored late evolutionary stages of Crab-like nebulae.

Dr. Arzoumanian, with Drs. W. Becker, and G. Kanbach (Max Planck Inst.), M. Weisskopf, F. Elsner, A. Tennant, and S. O'Dell (NASA MSFC), D. Lorimer (U. Manchester), F. Camilo (Columbia U.), O. Reimer (Ruhr-Universitat) Bochum, and D. Swartz (USRA/NASA MSFC), described a multi-wavelength search for a counterpart to the brightest unidentified gamma-ray source, 3EG J2020+4017 in the G78.2+2.1 supernova remnant. New X-ray and radio observations of the gamma-Cygni field with the Chandra X-ray Observatory and the Green Bank Telescope were made, and archival ROSAT data were re-analyzed. With Chandra it became possible to measure the position of the putative X-ray counterpart RX J2020.2+4026 with sub-arcsec accuracy, and to derive its spectral characteristics; these observations demonstrated that RX J2020.2+4026 is associated with a field K star and therefore is unlikely to be the counterpart of the bright gamma-ray source as had been previously suggested. A subsequent GBT radio pulsar search covered the complete 99% EGRET likelihood contour of 3EG J2020 +4017 with a sensitivity limit of L_820 $\sim$ 0.1 mJy kpc 2, lower than for most deep searches. If there is a pulsar operating in 3EG J2020+4017, this sensitivity limit suggests that the pulsar either does not produce significant amounts of radio emission or that its geometry prevents the radio beam from intersecting the line of sight. Finally, re-analysis of archival ROSAT data yielded a flux upper limit for a putative point-like X-ray source located within the 68% confidence contour of 3EG J2020+4017, which was used to constrain the properties of any neutron star associated with the remnant.

Dr. Jahoda, with Dr. A. Rots (Harvard Smithsonian Center for Astrophysics) and Prof. A. Lyne (U. Manchester), published the results of an eight-year campaign to compare the arrival times of pulse from the Crab pulsar in the X-ray and radio bands. These data, from Jodrell Bank Observatory and the RXTE PCA, determine a persistent difference (greater than 300 micro-sec) between the peak of the X-ray pulse and the peak of the radio pulse.

2.4 Gravitational Wave Astrophysics

Over the past year, commissioning efforts at the LIGO observatories have resulted in sensitivity of the LIGO detector reaching a factor of 2 of design, over its entire measurement bandwidth. This year has also seen the publication by the LIGO Scientific Collaboration of the first set of upper limits derived from the LIGO detectors for inspiral, burst, pulsar and stochastic wave background sources. Drs. Camp and Cannizzo have taken part in setting an upper limit for gravitational radiation from GRB030329, as well as the development of a time-domain algorithm for the detection of non-linear burst signals in the LIGO data stream.

Dr. J. Baker and Dr. J. Centrella, with collaborators at several universities, have established a Mock LISA Data Archive. The goal of the archive is to facilitate community development of data analysis techniques applicable to the LISA mission. (See http://astrogravs.nasa.gov/)

Dr. Watts has been investigating the effect of differential rotation on the oscillations and stability of neutron stars. This work, carried out in collaboration with Drs. N. Andersson and R. Williams (U. Southampton, UK) and Dr. D. I. Jones (Penn State), is motivated by the fact that vibrating neutron stars are a promising source of gravitational waves. Of particular interest are two phenomena unique to differentially rotating systems; dynamical shear instabilities, and the existence of a co-rotation band (a frequency band in which mode pattern speed matches the local angular velocity). They have found a new dynamical shear instability mechanism that operates when modes cross into the co-rotation band if the degree of differential rotation exceeds a certain threshold. They have also resolved the nature of stable oscillations within the co-rotation band. The band gives rise to a continuous spectrum whose collective physical perturbation exhibits complicated temporal behavior. In addition they have discovered the existence of modes within the continuous spectrum that appear physically indistinguishable from the discrete modes outside the band, despite the apparently singular nature of their eigen functions

2.5 Black Hole Astrophysics

Drs. Baker, Centrella, and Choi, along with B. Imbiriba and D. Fiske are applying the techniques of numerical relativity to carry out more refined gravitational wave source modeling. They have developed computational techniques for finite difference solutions of Einstein's gravitational field equations using Adaptive Mesh Refinement (AMR) as implemented in the PARAMESH package. They have found that the fully nonlinear gravitational field simulations of black hole systems can be successfully evolved if higher order interpolation methods are applied at the refinement boundaries. They are currently applying this code to studies of binary black hole systems, with the particular goal of supporting the LISA mission.

The group is also involved in the Lazarus project, an effort producing approximate models for gravitational waves binary black hole systems using a combined approach involving numerical simulation together with perturbation theory techniques in the regimes where they are applicable.

2.6 Galactic Binaries

Drs. Shrader and Titarchuk have undertaken a study to model the broad-band high-energy continuum of low-hard state galactic black holes in the context of Comptonization in a wind outflow. An analytic model has been developed, coded, and imported into the XSPEC spectral analysis package for application to observational data. A second revision of the code takes into account effects of Compton recoil. A paper describing the model, and its application to observational data, was recently accepted for publication in the ApJ.

Drs. Shrader and Titarchuk have carried out a study to compare the hard-to-soft state spectral transitions in black-hole X-ray binaries to those in certain neutron star X-ray binaries. This could lead to a diagnostic, which can distinguish, between black hole and neutron stars in systems that do not exhibit bursts, periodic or quasi-periodic phenomenon, notably Cygnus X- 3.

Drs. Shrader and Sturner are studying the high-energy spectral properties of the galactic black-hole candidate XTE J1550-56, which was observed as an INTEGRAL target of opportunity in 2003. It is also frequently covered by the INTEGRAL Core program Galactic scan and deep exposure observations. The 2003 outburst of this source seems to exhibit the unusual characteristic that the source remains in the hard spectral state throughout, and that the turn-on of the hard emission precedes that of the soft X-rays.

Dr. Mukai with Drs. Gabriel Pratt (MPE), Barbara Hassal (Univ. Central Lancashire), Tim Naylor (Univ. Exeter), and Janet Wood (Keele Univ.) has analyzed the XMM-Newton observation of the nova-like cataclysmic variable, UX UMa, which is deeply eclipsing in the optical. They have identified two X-ray emission components through a combination of spectral and timing analyses. The soft component is uneclipsed, while the hard component is. The latter is presumably from the boundary layer, while the former may be due to scattering in an accretion disk wind.

Dr. Mukai with Dr. Coel Hellier (Keele Univ.) has analyzed the Chandra HETG data on 5 magnetic cataclysmic variables, focusing on the Fe Kalpha lines, which are clearly separated into H-like, He-like, and fluorescent components. They do not confirm the earlier results that the thermal lines in some systems are broad. Instead, there are hints of structures within the thermal components.

Drs. Still and Boyd measured the historical precession rate of the accretion disk in the X-ray binary Hercules X-1 using data from the RXTE and CGRO missions. They found that the precession rate has switched during several occasions over the past 15 years at times, which coincide with the sources anomalous low states. These phenomena appear to be geometric in nature rather than resulting from accretion states.

Dr. Still with Dr. G. Hussain (CfA) have measured the coronal abundances of the post-common envelope binary and Hyades cluster member V471 Tau. They find evidence for an inverse first-ionization potential effect from an overabundance of coronal Neon. Abundance ratios provide evidence for ion species deposited magnetically from photosphere to corona.

Dr. Strohmayer with Dr. D. Ballantyne (Canandian Institute for Theoretical Astrophysics) have used the Fe emission and absorption edge observed during a ''superburst'' from the low mass X-ray binary (LMXB) 4U 1820-30 to explore the real-time evolution of the accretion disk in this system. The line and edge energies in addition to their strength and width encodes information about the ionization state and extent of the inner accretion disk. The disk is seen to respond to the extreme X-ray illumination produced by the superburst. Near the peak of the burst the inner disk is highly ionized and puffed up into a more tenuous flow. At later times the data indicate that the disk fills back in to a radius close to the marginally stable orbit. The data also provide a constraint on the binary inclination of the system.

Dr. Strohmayer used observations with XMM-Newton to find the first X-ray emission lines from an ultra-compact, AM CVn binary. High-resolution observations of GP COM with the Reflection Grating Spectrometers (RGS) on XMM/Newton revealed emission lines from the elements nitrogen and neon. The Lyman alpha lines from the hydrogen-like species as well as the helium-like triplets of each element were detected. Nitrogen is overabundant compared to oxygen and carbon, and is an indication of nuclear processing (via the CNO cycle) in the mass donor. A multi- temperature plasma emission process is required to adequately model the spectrum. The emission lines are unresolved with the RGS, and suggests an origin in a boundary layer close to the surface of the accreting white dwarf. Higher signal-to-noise detections of the helium-like triplets should allow for more precise density and temperature diagnostics of the emitting plasma.

Dr. Strohmayer used Chandra observations to detect and study the X-ray counterpart to the most compact known AM CVn binary, ES Cet. This accreting white dwarf binary system has the shortest orbital period of confirmed systems of this type, just 10.3 minutes. The Chandra data reveal a point-like X-ray source within 1 arcsec of the known optical position. The spectrum is relatively hard, given the expectation of a soft thermal spectrum thought to be produced at the high mass accretion rates expected for such a short orbital period. The X-ray spectrum shows evidence for line features at 470 and 890 eV, which might be lines from nitrogen and neon. The source shows no evidence for X-ray variability at the 10.3 minute orbital period.

Dr. Strohmayer used X-ray observations with Chandra to further explore frequency evolution in the ultra-compact candidate V407 Vul (RX J1914.4+2456). New Chandra data confirm that the object's 9.5 minute X-ray period is decreasing at a rate similar to that, which could be expected due to loss of gravitational radiation from the system.

Although the magnitude and sign of the torque could be due to gravitational radiation, the presence of substantial (factor of 3) X-ray flux variability, as well as excess phase timing residuals, could also be produced in a scenario whereby the observed period is the spin period of a white dwarf, and fluctuations in the accretion rate account for the flux variability and phase timing noise. Further monitoring of the system could test this hypothesis.

Dr. Strohmayer, with Drs. Markwardt, M. C. Miller (U. of Maryland), and S. Bhattacharyya (U. of Maryland), have used observations of 314 Hz pulsations during X-ray bursts from the accreting millisecond pulsar XTE J1814-338 to place constraints on the structure of the neutron star in this system. Burst oscillation profiles from XTE J1814-338 were the first to show significant harmonic structure. The observed pulse profiles as a function of photon energy were compared to state of the art model calculations of photon emission and propagation from the surface of a neutron star. The model includes realistic calculations of the structure of spinning neutron stars for several different equations of state, as well as a full relativistic treatment of photon propagation from the surface.

Dr. Uttley, with Dr. McHardy (Southampton) and Dr. Vaughan (Leicester) studied the nature of aperiodic X-ray variability in the black hole X-ray binary Cygnus~X-1, showing it to be non-linear with a lognormal flux distribution. The same pattern can be extended to explain the apparently non-linear X-ray variability observed in some AGN, and suggests that the variability process is multiplicative, with additive models, such as simple shot-noise or self-organized criticality, being ruled out.

2.7 Supernovae and Supernova Remnants

Dr. Moskalenko with Drs. Andrew W. Strong (MPI-Extraterrestrishe Physik, Germany), Olaf Reimer (Bochum University, Germany), Seth Digel (Stanford), and Roland Diehl (MPI-Extraterrestrishe Physik, Germany) presented a solution to the apparent discrepancy between the radial gradient in the diffuse Galactic gamma-ray emissivity and the distribution of supernova remnants, believed to be the sources of cosmic rays. Recent determinations of the pulsar distribution have made the discrepancy even more apparent. The problem is shown to be plausibly solved by a variation in the CO-to-N(H2) scaling factor. If this factor increases by a factor of 5-10 from the inner to the outer Galaxy, as expected from the Galactic metallicity gradient, then the source distribution required to match the radial gradient of gamma-ray can be reconciled with the distribution of supernova remnants as traced by current studies of pulsars. The resulting model fits the EGRET gamma-ray profiles very well in longitude, and reproduces the mid-latitude inner Galaxy intensities better than previous models.

Dr. Harrus with Dr. Patrick Slane (Harvard-Smithsonian Center for Astrophysics), Dr. John Hughes (Rutgers University) and Dr. Paul Plucinsky (Harvard-Smithsonian Center for Astrophysics) studied the X-ray emission of the Supernova Remnant G18.95-1.1. They find that the emission is heavily absorbed, predominantly thermal, and can be best described by an non-equilibrium ionization model. Above 4 keV, we identify a small region of emission located at the tip of the central, flat-spectrum bar-like feature in the radio image.

Dr. Hwang in collaboration with Dr. J. Martin Laming (Naval Research Laboratory) and 20 other scientists from various institutions carried out an initial study of a 1 Ms observation of Cassiopeia A by the Chandra X-ray Observatory. Their study showed the presence of bipolar jets of ejecta with similar, Si-rich and Fe-poor compositions and confirmed the presence of pure Fe regions elsewhere in the remnant. The explosion mechanism is favored as the origin jet ejecta structure, as opposed to bipolar structure in the circumstellar medium. The neutron star at the center of the remnant is shown to have a pure blackbody spectrum and no spatial extent.

Drs. Hwang and Petre collaborated with Kathryn Flanagan (MIT) in an investigation of shock interactions in the Puppis A supernova remnant. Their study with the Chandra Observatory revealed hardness structure in the X-ray plasma that can be attributed to the remnant's interaction with a complex, cloudy and dense medium to the east.

2.8 Gamma Ray Bursts

Drs. Band, Norris and Bonnell have constructed and posted a gamma-ray burst database with redshifts, peak fluxes and spectra using the lag-luminosity relation. They are now using this database to address various questions about the burst population.

Dr. Band has been analyzing the sensitivity of the proposed EXIST mission for the detection of gamma-ray bursts.

Drs. Band, Norris and Bonnell have been developing burst trigger algorithms for GLAST's two detectors. For the LAT detector Dr. Band developed a binned method while Drs. Norris and Bonnell developed an unbinned method. Dr. Band has been working with the GBM team in designing the GBM's burst trigger.

Drs. Cannizzo and Gehrels, with Dr. Vishniac (JHU) are continuing their study of the propagation of relativistic ejecta through a uniform external medium, as representing a ''fireball'' that produces a gamma-ray burst. Extensive testing with increasing resolution is being carried out, using the 3D relativistic hydrodynamics code written by Cannizzo. Current efforts involve attempting to reproduce the classical Blandford-McKee solution for the propagation of a relativistic blast wave. Also, in collaboration with Brian Morsony, a graduate student of Dr. Begelman at the Univ. of Colorado at Boulder, a 2D code with cylindrical symmetry has been written and testing has begun.

Dr. Holland collaborated with Drs. K. Stanek and T. Matheson (Harvard) on a project to study GRB030329/SN2003dh, discovering a link between long-soft gamma-ray bursts and Type Ic supernovae. He also collaborated with Drs. A. Filippenko (Berkeley), J. Tonry (Hawaii) and B. Williams (Washington) on a study of high-redshift supernovae. Their results support a cosmology with a cosmological constant of 0.7 and constrain the value of the equation of state.

Dr. Reeves, together with Drs. Vaughan, Willingale, O'Brien, Osborne, Levan, and Tedds (University of Leicester), Dr. Watson (University of Copenhagen) in collaboration with Drs. Santos-Lleo, Rodriguez-Pascal and Schartel (XMM-Newton Science Operations Center, Spain) observed the X-ray afterglow of the unusually nearby Gamma-Ray burst 031203. The XMM-Newton observations revealed an expanding halo of X-ray emission around the decaying afterglow of this Gamma-Ray burst. The halo was attributed to scattering of a large column of dust, in two distinct slabs approximately 1 kpc away from the observer, towards the direction of the Gum nebula. The brightness of the halo implied a soft X-ray pulse was emitted from this burst, of similar flux to the Gamma-Ray burst itself. A subsequent paper also showed that GRB 031203 was an exceptionally low luminosity burst, 3-4 orders of magnitude lower than expected, with properties similar to those observed in X-ray flashes.

2.9 Active Galaxies

Dr. Stecker has continued work of the absorption of very high energy gamma-rays by pair production interactions with intergalactic IR, optical and UV photons. This work has lead to a derivation of the source spectrum of multi-TeV gamma-rays from Mkn 501 during the 1997 are by Dr. O. C. De Jager (Potchefstroom Univ., South Africa) and Stecker. The fact that the expected absorption is seen in this spectrum up to 20 TeV has allowed Stecker and Prof. Sheldon Glashow (Boston Univ.) to place stringent limits on the violation of Lorentz invariance. Stecker has continued work on putting other constraints on Lorentz invariance violation and implications for quantum gravity theory, publishing one paper in Astroparticle Physics and another paper with T. Jacobson, S. Liberati and D. Mattingly (U. Maryland) in *Physical Review Letters*.

Dr. Georganopoulos continued his investigations of high-energy emission from sources where bulk relativistic flows are thought to exist, and in particular of the Chandra detected quasar jets, and the TeV emitting blazars. Drs. Georganopoulos and Kazanas developed models that unify the current observations of these sources under a scheme according to which the relativistic flows in these sources are relativistic and decelerating. They are also currently working on using the newly gained understanding that quasar kpc scale jets remain relativistic to examine if these jets are composed of electrons and protons, or of electrons and positrons.

Drs. Shrader, Tueller and Krimm have been awarded INTEGRAL observing time to study a sample of Seyfert-1 active galactic nuclei, which are among a list of objects to be monitored by Swift. The simultaneous broadband observations are required to understand the complex processes in these AGN. Swift can produce high-resolution hard X-ray spectroscopy (particularly of the Fe K lines) and UV GRISM spectroscopy to provide context for the INTEGRAL observations. Swift can also provide long-term monitoring to place the INTEGRAL measurements on a longer term light-curve.

Drs. Boldt, Hamilton, and Loewenstein have studied nearby dormant bulge-dominated galaxies and examined the growth rates of their central black holes. Using the time since the last major galactic merger as a measure of galaxy age, they have looked at the trend of black hole mass growth relative to bulge mass. The study puts limits on the long-term growth rate of black holes in inactive galaxies. It could also show what fraction of the black hole's accreted mass originates inside the host and what is in-fall from the intergalactic medium or minor galactic mergers.

Dr. Hamilton with Drs. S. Casertano (STScI) and D. Turnshek (U. Pittsburgh) have found that the fundamental plane for quasars changes geometry when looking at different QSO classes. The plane is a relationship between a quasar host's effective surface magnitude and radius and the nuclear luminosity. Within this parameter space, quasars lie in a thin plane. Radio-loud and radio-quiet quasars have planes with opposite slopes. The relationship between host and nucleus is reversed between these samples. The physical interpretation of the QSO fundamental plane may involve the fueling mechanism at the quasar core.

Dr. Loewenstein is investigating the connections between supermassive black holes, the evolution of active galactic nuclei, and the heating of the universe. Theoretical models, constrained by the observed evolution of the active galactic nuclei X-ray luminosity function and local supermassive black holes mass function, indicate that significant black hole growth occurs at low redshift, and at low radiative efficiency. Outflows associated with this growth may be a significant source of heating intergalactic and intracluster gas.

Dr. Markowitz with Dr. Rick Edelson (UCLA) used RXTE archival data to systematically quantify Seyfert 1 X-ray variability on multiple time scales, corroborating previously studied scaling relations between black hole mass, luminosity and variability characteristics in Seyfert 1s, and additionally probing Seyfert 1 X-ray spectral variability.

Dr Reeves and Drs George, Turner and Yaqoob, together with Dr Pounds (University of Leicester, UK) and Dr Nandra (Imperial College, UK) reported on the iron K line profile of the bright, nearby Seyfert 1 galaxy, NGC 3783, from a long 240ks XMM-Newton observation. The line profile obtained exhibited two strong narrow peaks from iron K α and β, originating from distant Compton-thick matter.

For the first time in this source, a strong absorption line from highly ionized iron (at 6.67 keV) was detected and the depth of the feature appeared to vary with time, the absorption being strongest when the continuum flux was highest. The iron absorption line arises from the highest ionization component of the known warm absorber in NGC 3783, within 0.1 pc of the nucleus. No requirement was found for a relativistic iron line component from the inner accretion disk.

Dr. Reeves, together with Drs. Pounds, King, Page and O'Brien (University of Leicester) found evidence for an unusually high velocity outflow from XMM-Newton observation of the narrow line quasar PG 1211+143. Blue-shifted absorption lines were observed from H and He-like ions of Fe, S, Mg, Ne, O, N and C. The observed line energies indicated an ionized outflow velocity of 24000 km/s. It was found that if the origin of this high-velocity outflow lies in matter being driven from the inner disc, then the flow is likely to be optically thick within a radius of 130 Schwarzschild radii, providing an explanation for the big blue bump (and strong soft X-ray) emission in PG1211+143.

Dr. Uttley, with Dr. McHardy (Southampton) used extensive RXTE monitoring observations to investigate the X-ray variability power spectral density (PSD) of the broad line Seyfert 1 galaxy NGC 3227, showing it to be consistent (when scaled by black hole mass) with the PSD shape of X-ray binaries in the high/soft state, and not the low/hard state. This result was unexpected, because it was previously assumed that Narrow Line Seyfert 1 galaxies are the best AGN analogs of X-ray binaries in the high/soft state.

Dr. Yaqoob and Ms. U. Padmanabhan (JHU) published the results of a study of the Fe K-alpha emission line in a sample of 15 Seyfert galaxies observed by the Chandra High Energy Grating Spectrometer, affording the highest spectral resolution data for this emission line to date ($\sim$ 1800 km/s FWHM). The results show in most cases the core of the line is unresolved and its energy indicative of neutral Fe. The results allow one to better model CCD data for the broad, relativistic part of the Fe K-alpha line and this modeling is currently underway. Dr. Yaqoob, with Dr. B. McKernan (JHU and UMCP) also published more detailed Chandra grating results for the brightest member of the sample, IC 4329a, in which a double-peaked Fe K-alpha line profile was discovered, part of which may be from a relativistic accretion disk.

Dr. Yaqoob, with Drs. B. McKernan (JHU and UMCP), Drs. George, Mushotzky and Turner, published a study of the radio-loud quasar 3C 120, in which a soft X-ray absorption feature was found, attributed to either a jet or the warm/hot intergalactic medium (WHIGM).

Dr. Yaqoob, with Drs. B. McKernan (JHU and UMCP), Drs. George, Mushotzky, and Turner, published a detailed Chandra grating study of the kinematics and physical conditions in the photoionized absorber in the Seyfert galaxy NGC 4593.

Dr. Yaqoob, with Drs. George, Kallman, Weaver, Turner, and Ms. Padmanabhan (JHU) published a paper reporting the discovery of narrow emission lines due to Fe I, Fe XXV, and Fe XXVI in the Seyfert galaxy NGC 7314. The data indicate that the ionization structure of the compact line emission region is rapidly variable so this source may be useful as a laboratory to study accretion disk structure with future missions.

2.10 Cosmic Rays

Dr. Jones has continued to work with Dr. Donald Ellison of North Carolina State University and Dr. Matthew Baring of Rice University in modeling the acceleration of charged particles by collisionless plasma shocks such as those surrounding supernova remnants. He has also continued to work with Dr. Vladimir Ptuskin of the Russian Academy of Sciences and the University of Maryland, College Park and Dr. Moskalenko on modeling the propagation of cosmic rays in the galaxy and their production of secondary particles and gamma rays. Some further work was conducted on the nature of the cosmic-ray knee with Drs. Demos Kazanas and Robert Streitmatter of this laboratory and was reported at the April meeting of the American Physical Society in Denver.

Dr. Moskalenko with Dr. Andrew W. Strong (MPI-Extraterrestrishe Physik, Germany) continue to develop a GALPROP model of Galactic cosmic-ray propagation and production of diffuse gamma rays, and to make it suitable for the analysis and interpretation of data of near future experiments (GLAST, AMS, Pamela, BESS-Polar, Super-TIGER etc.). GALPROP is the ''realistic'' 3-dimensional numerical model and computer code of cosmic-ray propagation in the Galaxy and production of diffuse gamma rays; this is the most advanced model to date. It includes in a self-consistent way all cosmic ray species (stable and long-lived radioactive isotopes from H to Ni, antiprotons, positrons and electrons, gamma rays and synchrotron radiation), all relevant processes and reactions, and details of the Galactic structure. Its results (and the code) are widely used as a basis for many studies in astrophysics, particle physics, and cosmology, such as search for Dark Matter signatures, origin of the elements, the spectrum of Galactic and extragalactic diffuse gamma ray emission, heliospheric modulation studies etc.

Drs. Moskalenko and Jones, with Drs. Andrew W. Strong (MPI-Extraterrestrishe Physik, Germany), V. S. Ptuskin (IZMIRAN), and Stepan G. Mashnik (LANL) studied the damping (dissipation) of interstellar MHD waves on the small scale by cosmic rays. The energy density of cosmic-ray particles is about 1 eV cm_3 and is comparable to the energy density of interstellar radiation field, magnetic field, and turbulent motions of the interstellar gas. This makes cosmic rays one of the essential factors determining the dynamics and processes in the interstellar medium. The stochastic acceleration of cosmic rays by MHD waves is accompanied by the damping (dissipation) of waves, which changes the wave spectrum that in turn affects the cosmic-ray transport thus producing less secondary nuclei at low energies. This effect may present an alternative explanation to the observed peaks of secondary to primary nuclei ratios at a few GeV/nucleon.

2.11 Our Galaxy

Dr. Moskalenko with Drs. Andrew W. Strong (MPI-Extraterrestrishe Physik, Germany), and Olaf Reimer (Bochum University, Germany) used the GALPROP model to study the compatibility of some current models of the diffuse Galactic continuum gamma rays with EGRET data. A set of regions sampling the whole sky is chosen to provide a comprehensive range of tests. The range of EGRET data used is extended to 100 GeV. They confirm that the ''conventional model'' based on the locally observed electron and nucleon spectra is inadequate, for all sky regions. A conventional model plus hard sources in the inner Galaxy is also inadequate, since this cannot explain the GeV excess away from the Galactic plane. Models with a hard electron injection spectrum are inconsistent with the local spectrum even considering the expected fluctuations; they are also inconsistent with the EGRET data above 10 GeV. A new model was presented which fits the spectrum in all sky regions adequately. Secondary antiproton data were used to _x the Galactic average proton spectrum, while the electron spectrum is adjusted using the spectrum of diffuse emission itself. The derived electron and proton spectra are compatible with those measured locally considering fluctuations due to energy losses, propagation, or possibly details of Galactic structure. This model fits the gamma-ray spectrum much better and to the highest EGRET energies. It gives a good representation of the latitude distribution of the gamma-ray emission from the plane to the poles, and of the longitude distribution. The secondary positrons and electrons in cosmic rays make an essential contribution to Galactic diffuse gamma-ray emission.

Drs. Kuntz and Snowden are analyzing XMM spectra of the diffuse emission from the hot Galactic ISM. They are currently concentrating on spectra from lines of sight through Baade's Window, the Galactic Bulge, and the Loop I superbubble, in order to determine the temperature gradient of the Galactic Bulge. Although the spectra in these directions are complicated by multiple emission/absorption components along the line of sight, there is some evidence of a temperature gradient. The same team is also studying spectra of the Local Hot Bubble (LHB) to determine whether there is a temperature gradient within the LHB.

Dr. Kuntz and Dr. R. Shelton (UGa.) are analyzing XMM spectra taken along several lines of sight through the Galactic Halo. These lines of sight have complementary FUSE observations of O VI. Analysis will allow a complete characterization of the thermal state of the Galactic Halo in these lines of sight.

2.12 Normal Galaxies

Drs. Angelini and Loewenstein completed analysis and comparison of 2000 and 2003 Chandra X-ray Observatory observations of the population of X-ray binaries in the giant elliptical galaxy NGC 1399. A number of variable low-mass X-ray binaries are identified, including some candidate transient sources. Many of these are associated with globular clusters. An ultraluminous source declined in luminosity while maintaining a soft spectrum, as seen in some (high state) black hole binaries. This represents perhaps the most convincing single case of a black hole in a globular cluster.

The M101 Ms Collaboration (Drs. Kuntz, Snowden, Mukai, Pence, Y-H. Chu (UIUC), V. Kalogera (NWU) P. Bamby (SAO)) are obtaining a 1 Ms Chandra exposure of the nearby face-on spiral galaxy M101, which will allow detection of point sources to a limiting luminosity of a few times 10^{35} ergs/s. The bulk of the X-ray binaries will be detected by this exposure. The Ms exposure is segmented, with sub-exposures taken every two months, allowing the study of source variability. The X-ray data is complemented by a deep optical survey using the HST ACS for the identification of the optical counterparts of the X-ray sources; all HMXB with O and early B star companions, all LMXB in globular clusters, and nearly all background AGN are identifiable. The long Chandra exposure is revealing unprecedented detail of the diffuse emission. When finished, these data will allow a study of M101 to the same depth as current studies of M31.

2.13 Extragalactic Background

Dr. Moskalenko with Drs. Andrew W. Strong (MPI-Extraterrestrishe Physik, Germany), and Olaf Reimer (Bochum University, Germany) re-evaluated the extragalactic gamma-ray background based on a new model of the Galactic component of gamma rays that gives an accurate prediction of the observed EGRET intensities in the energy range 30 MeV-50 GeV away from the Galactic plane. It was found that for some energies previous work underestimated the Galactic contribution at high latitudes and hence overestimated the background. The new background spectrum shows a positive curvature similar to that expected for models of the extragalactic emission based on the blazar population or annihilations of the neutralino dark matter.

Drs. Andrew Chen (Consorzio Interuniversitario per la Fiscia Spaziale, Torino), Reyes and Ritz demonstrated quantitatively how gamma rays can be used to measure the density of optical-UV extragalactic background light (EBL) as a function of redshift. This is important because the EBL traces the start formation rate and is very difficult to measure directly. The technique will be enabled by GLAST, which should detect thousands of AGN over a large range of redshifts (to 4-5), and provides another interesting scientific connection between separated wavebands. The work was published in the *Astrophysical Journal*.

2.14 Background Sources

Dr. Kuntz has analyzed the temporal and spatial variation of the spectral shape of the XMM EPIC instrumental background, and has developed the databases and algorithms required to remove that background. These tools allow more complete analysis of diffuse emission that fills the instrument field of view, such as the diffuse Galactic emission or the cosmic background emission.

Drs. Jahoda and Markwardt, with Drs, M. Revnivtsev, M. Gilfanov, and R. Sunyaev (Max Planck Institute fur Astrophysik), studied the spectrum and normalization of the diffuse X-ray Background; other experiments disagree on the normalization despite agreement on the shape of the spectrum. This measurement contributed observations with the Proportional Counter Array experiment aboard RXTE.

2.15 Catalogs

Dr. Kuntz is constructing a catalogue of all sources detected by the XMM OM.

Dr. Jahoda, with Drs. M. Revnivtsev, S. Sasonov, and M. Gilfanov (Max Planck Institute fur Astrophysik), produced a catalog of sources observed with the PCA during slewing operations of the RXTE observatory. The catalog complements and extends towards lower flux the number-flux relationships measured by other collimated experiments.

2.16 Atomic Physics

Drs. Kallman and Palmeri with Drs. Bautista and Mendoza (IVIC, Venezuela) and with Dr. J. H. Krolik (Johns Hopkins University) calculate the effeciency of iron K line emission and iron K absorption in photoionized models using a new set of atomic data. These data are more comprehensive than those previously applied to the modeling of iron K lines from photoionized gases, and allow them to systematically examine the behavior of the properties of line emission and absorption as a function of the ionization parameter, density and column density of model constant density clouds. They show that, for example, the net fluorescence yield for the highly charged ions is sensitive to the level population distribution produced by photoionization, and these yields are generally smaller than those predicted assuming the population is according to statistical weight. They demonstrate that the effects of the many strongly damped resonances below the K ionization thresholds conspire to smear the edge, thereby potentially affecting the astrophysical interpretation of the absorption features in the 7-9 keV energy band. They show that the centroid of the ensemble of K-alpha lines, the K-beta energy, and the ration of the K-alpha(1) to K-alpha(2) components are all diagnostics of the ionizaton parameter of their model slabs.

Dr. Palmeri, with Dr. E. Biemont (Liege University/ Mons-Hainaut University, Belgium), with Drs. A. Derkatch, P. Lundin, S. Mannervik, D. Rostohar, P. Royen (Stockholm University, Sweden) and with Dr. L.-O. Norlin (Royal Institute of Technology, Sweden) have carried out an experimental investigation of the radiative lifetime of the metastable 4p(2)4p(4)(3P)4d 4D7/2 level in Kr II that shows an unusual situation regarding the importance of an M2 depopulation channel. While the first order M1 and E2 channels are expected to contribute in a dominant way to the decay, the experimental result, obtained using a laser probing technique on a stored ion beam, tau=0.57+/- 0.03 s, is far too short to be due to these channels according to our relativistic multiconfiguration Dirac-Fock calculation. Only if the second order contributions to the decay branches (including essentially the M2 contribution) are taken into account in the calculations the unexpected short lifetime could be explained.

3. OPERATIONAL ORBITAL FLIGHT MISSIONS

3.1 International Gamma-Ray Astrophysics Laboratory (INTEGRAL)

INTEGRAL (the International Gamma-Ray Astrophysics Laboratory) was launched in October 2002, and has been operating successfully since that time. It is the first of three planned successors to the highly successful Compton Gamma Ray Observatory (CGRO) mission - the others being the forthcoming NASA GLAST and Swift missions—offering better than order of magnitude improvements in spectral and spatial resolution. This is achieved through the employment of a germanium crystal spectrometer and a pixelated cadium telluride detection system with 16,384 detectors. It is expected that INTEGRAL will operate concurrently with Swift and GLAST for a period of at least several years. Major scientific results to date include unprecedented mapping of the Galactic Center 511-keV emission, revealing the source of the Galactic ridge hard-X-ray emission, and the discovery a population of highly absorbed X-ray binaries not readily detectable at lower energies. The US Guest Observer Facility (GOF) is at Goddard, and Goddard is also a Co-I institution for the spectrometer. The scientists involved are Drs. Teegarden (NASA Project Scientist), Gehrels (Mission Scientist), White (NASA ISDC Consortium Rep.), Shrader, Ebisawa, Sturner and Beckmann (GOF Staff Scientists).

3.2 Solar Anomalous and Magnetospheric Explorer (SAMPEX)

Dr. von Rosenvinge is Project Scientist for and a Co-Investigator on the SAMPEX small explorer mission launched in 1992. SAMPEX was, until recently, in an extended mission phase to study both trapped and interplanetary anomalous cosmic rays, the charge states of solar energetic particles, and the acceleration of magnetospheric particles and their effects on the upper atmosphere. SAMPEX has documented the build-up of energetic particles in the magnetosphere which frequently accompany satellite failures. A very successful model for predicting MeV electron fluxes at geosynchronous orbit based solely on solar wind measurements as input was developed at the U. of Colorado at Boulder. Measurements in solar events using the geomagnetic cut-off show an unexpected correlation between the mean iron charge state and the observed iron to oxygen ratio. The extended mission phase formally ended on July 1, 2004. Efforts are underway to continue taking SAMPEX data. In addition, NASA Headquarters has funded an effort to archive SAMPEX data going back to 1992 and making it available to the public through the World Wide Web (SAMPEX was launched before this became a standard practice).

3.3 The Energetic Particle Acceleration, Composition and Transport Experiment (EPACT) on the ISTP/Wind Spacecraft

Dr. von Rosenvinge is the Principal Investigator for the Energetic Particles: Acceleration, Composition, and Transport (EPACT) experiment, developed in conjunction with Drs. Reames and Barbier for the Wind spacecraft and launched in November, 1994. Dr. G. Mason (UMCP) is also a co-investigator. Sensitivity for low energy particles has been increased by two orders of magnitude, so that high sensitivity studies of the anomalous component, Corotating Interaction Regions and 3_{He}-rich events have been possible. Trans-iron nuclei were discovered in impulsive solar particle events. This discovery, subsequently confirmed by the ULEIS instrument on the ACE spacecraft, depended on both high sensitivity and the fact that the trans-iron elements are enhanced relative to normal solar abundances by a factor of approximately one thousand. This enhancement had been speculated upon for years, but has only recently been confirmed.

3.4 Interplanetary Gamma-Ray Burst Timing Network (IPN)

The interplanetary GRB network (IPN) continues to be a primary source of precise gamma ray burst localizations. These source fields are distributed by the GRB Coordinates distribution Network (GCN) immediately upon receipt of the data, with varying delays of a few hours or more. The IPN in 2004 involves three space probes at mutually great separations: the Konus GRB experiment on the GGS-Wind spacecraft (Dr. E. Mazets, St. Petersburg, Russia, PI), the Mars Odyssey, with both a gamma-ray-sensitive neutron detector (I. Mitrofanov, Moscow, PI) and a gamma-ray spectrometer (W. Boynton, Arizona, PI), and Ulysses (Dr. K. Hurley, UC Berkeley, PI)—which at the time of writing is (hopefully) temporarily inactive. Additional near-Earth GRB data are also provided by HETE-2, R-HESSI and R-XTE missions, depending on the event circumstances. The Konus data are extracted from the GGS-Wind telemetry at Goddard automatically, then incorporated into the IPN analyses and delivered by the GCN. The GRB localizations of the IPN, delivered to the community by the GCN, run by S. Barthelmy, have enabled many follow-on GRB afterglow studies. This combination also assisted BeppoSAX and HETE-2 by calibrating and confirming their localizations. The IPN, in parallel with HETE-2 and also INTEGRAL, will soon provide this service for Swift, the next-generation GRB mission.

3.5 Advanced Composition Explorer (ACE)

The Advanced Composition Explorer (ACE) was successfully launched on August 25, 1997. LHEA scientists involved include Drs. De Nolfo and von Rosenvinge (Project Scientist). ACE includes two instruments which were developed jointly by Caltech, GSFC, and Washington U. in St. Louis. The Cosmic Ray Isotope Spectrometer has made unprecedented new measurements of heavy cosmic ray isotopes. These measurements include observations of the isotopes ^{59}Ni and ^{59}Co which suggest that there is a delay of $\sim 10^5$ years or more between the synthesis of ^{59}Ni by supernovae and its acceleration to cosmic ray energies. The Solar Isotope Spectrometer (SIS) has measured isotopes in the Anomalous Cosmic Rays (ACRs) and in solar energetic particle events. The large collection power and resolution of SIS have allowed it to observe many previously unmeasured rare elements as well as to make measurements of different isotopes. The isotopic abundances are observed to vary significantly from event to event.

3.6 Rossi X-ray Timing Explorer (RXTE)

The RXTE mission observes X-ray emitting compact objects, in order to study gravity in the strong-field regime, physics of ultra-dense matter and ultra-strong magnetic fields, and mass flows in accretion-powered systems. Dr. Swank is the Project Scientist. The satellite carries three instruments, the All Sky Monitor (MIT), the Proportional Counter Array (GSFC), and the High Energy X-Ray Timing Experiment (UCSD). The mission and satellite are operated by the Science and Mission Operations Centers at Goddard. Dr. Marshall is the director of the Science Operations Center. Dr. Corbet manages the Science Operations Facility, which carries out the observation planning and monitoring and instrument commanding. Dr. Boyd is the manager of the Guest Observer Facility (GOF) The GOF is responsible for making the RXTE data available to observers and for fielding questions asked by the observers.

Operating since 1996, RXTE continues in an extended mission phase, currently carrying out Cycle 9 observations and anticipating Cycle 10 proposals due September 20, 2004. The Senior Review of 2004 has authorized a budget for continued operations during the next two years, with termination after that, subject to reconsideration by the 2006 Senior Review. Small guest observer support grants were awarded for Cycle 9. Augmented support is anticipated for Cycle 10.

Information on the mission can be found at: http://xte.gsfc.nasa.gov/docs/xte/xte_1st.html. Links are given there for the 2004 Senior Review Proposal and for the presentation which Prof. Fred Lamb gave at the review.

The discovery in 2003 that two accreting millisecond pulsars have burst oscillations settled the debate of whether the oscillations tell us the spin frequency and that the spin frequency searches for additional millisecond pulsars are being intensified, along with the parts of black hole transient outbursts in which the X-ray emission is most intense and the high frequency oscillations most probably. RXTE continues to carry out both preplanned and target of opportunity proposals, including many coordinated with other space- and ground-based observatories, from radio through TeV.

3.7 X-ray Multi-mirror Mission (XMM-Newton)

The ESA XMM-Newton X-ray observatory, launched in 1999 December, continues to operate well and is in its Guest Observer phase of operations, which also includes Target of Opportunity observations. XMM-Newton covers the 0.1 - 15 keV energy range with large effective area, moderate angular resolution (15″), and moderate (CCD) and high (grating) spectral resolution. XMM-Newton also includes an Optical Monitor for simultaneous coverage of the UV/optical band. Information about the project can be found in the NASA/GSFC Guest Observer Facility web pages (http://xmm.gsfc.nasa.gov).

XMM-Newton data are flowing to the community both through the GO program (where US scientists continue to be rather successful) and through the project archive. All calibration, performance verification, and science verification data sets are public, and both GT and GO data sets become public as their proprietary periods expire. Archive data are available through the SOC as well as a mirror site at GSFC. New data are typically delivered to Guest Observers within a few weeks of the completion of the observation.

The current version of the data reduction software (SAS V6.0) is both robust and complete although improvements continue to be made. The instrument calibrations are good (typically good to within 10%), and also continue to be improved.

The NASA/GSFC XMM-Newton Guest Observer Facility supports US participation in the project. This includes supporting the submission of science observing proposals (the project is currently in its third GO cycle with AO-4 about to open), providing help in the analysis of the science data, and managing the GO grant process. The GOF also participates in the continued development of the Standard Analysis Software (SAS). GOF scientists Drs. Snowden and Immler, under the direction of Dr. Mushotzky, work closely with all team members, both in the US and in Europe.

The US XMM-Newton project did well in the 2004 Senior Review. Funding will be maintained for GOF and instrument team operation, and will be increased in some areas of Guest Observer support. An XMM-Newton archive program will be added to the ADP.

4. FUTURE FLIGHT MISSIONS

4.1 Laser Interferometer Space Antenna (LISA)

Gravitational radiation has the potential of providing a powerful new window on the Universe for observing the behavior of astronomical systems under conditions of strongly non- linear gravity and super-high velocities. Because of seismic and gravity gradient noise on Earth, searches for gravitational radiation at frequencies lower than 10 Hz must be done in space. The frequency range 10^{-4} to 1 Hz contains many of the most astrophysically interesting sources. In this band, predicted emission includes that associated with the formation or coalescence of massive black holes in galactic nuclei. Laser interferometry among an array of spacecraft in heliocentric orbit with separations on the order of a thousand Earth radii will reach the sensitivity to observe low frequency gravitational radiation from likely sources out to cosmological distances, and will be an important complement to the ground-based experiments already being constructed. The LISA observatory for gravitational radiation is a cluster of three spacecraft that uses laser interferometry to precisely measure distance changes between widely separated freely falling test masses housed in vehicles situated at the corners of an equilateral triangle 5×10^6 km on a side. It is a NASA/ESA mission that is part of the NASA Beyond Einstein Program. The NASA scientists involved in LISA are: Drs. Centrella, Camp, Merkowitz, Macnamara, Numata, Stebbins (LISA Project Scientist) and Teegarden.

4.2 Advanced Compton Telescope (ACT)

The Advanced Compton Telescope (ACT) is a NASA mission to perform gamma-ray spectroscopic observations in the 200 keV to 30 MeV range. The primary scientific objective is to determine what causes stellar explosions and how elements are created in such events. ACT is being studied as a NASA Vision Mission in the Universe Division of the Science Mission Directorate at NASA HQ. This year ACT was selected and funded for a one-year concept study. Prof. Steve Boggs (UC Berkeley) is the ACT Principal Investigator. Team members at Goddard are Drs. Bloser, Gehrels, Hunter and Tueller.

4.3 Swift

The Swift gamma-ray burst MIDEX proposal was selected by NASA October 14, 1999. The observatory will be launched in October 2004 for a nominal two-year lifetime. Swift is an international payload consisting of wide and narrow field-of-view instruments with prompt response to gamma ray bursts. A 1.4-steradian wide-field gamma-ray camera will detect and image > 100 gamma-ray bursts per year with 1-4 arcmin positions. The Swift spacecraft then slews automatically in 20-75 seconds to point narrow-field X-ray and UV/optical telescopes at the position of each gamma-ray burst to determine arcsecond positions and performs detailed afterglow observations. The goal of the mission is to determine the origin of gamma-ray bursts and to use bursts to probe the early universe. The mission is managed at Goddard. Dr. Gehrels is the Principal Investigator, Dr. White chairs the Executive Committee and Dr. John Nousek is the lead scientist at Penn State, the prime US university partner. Key hardware contributions are made by international collaborators in the UK and Italy. This year the instruments were integrated on the observatory and the observatory was subjected to environmental testing. All testing was successfully completed and the observatory shipped to the KSC launch site on July 27, 2004.

4.4 Gamma-ray Large Area Space Telescope (GLAST)

Drs. Gehrels, Hartman, McEnery, Moiseev, Norris, Ormes (GSFC, Director of Space Sciences), Ritz, and Thompson are GSFC members of a large, international collaboration (Prof. P. Michelson of Stanford is the PI) that was selected to build the Large Area Telescope (LAT) main instrument for the Gamma-ray Large Area Space Telescope (GLAST), the next-generation high-energy gamma-ray mission. With a large field of view (2.4 sr), large peak effective area (> 8000 cm^2, greatly improved point spread function (< 0.15 degrees for $E > 10$ GeV), and unattenuated acceptance to high energies, GLAST will measure the cosmic gamma-ray flux in the energy range 20 MeV to > 300 GeV with unprecedented precision and a factor 40 better sensitivity than the previous EGRET detector. The launch is planned for 2007. GLAST will open a new and important window on a wide variety of high energy phenomena, including supermassive black holes and active galactic nuclei; gamma-ray bursts; supernova remnants; and searches for new phenomena such as supersymmetric dark matter annihilations. The instrument consists of a large effective area Si-strip precision converter-tracker, an 8.4 radiation length CsI hodoscopic calorimeter, and a segmented plastic tile anticoincidence detector (ACD).

GSFC is the lead institution responsible for the LAT ACD, including all hardware and readout electronics. Dr. Thompson, the ACD subsystem manager, and Drs. Moiseev and Hartman are designing the flight unit. An engineering model for the ACD was constructed and used in a flight-scale GLAST tower beam test in 1999. This same tower was used in a balloon flight in 2001, for which Dr. Thompson was the leader. The GLAST ACD fight unit is now under construction and test.

Drs. Moiseev, Ritz and McEnery are performing instrument and science simulations. Dr. Norris is helping to coordinate the LAT team gamma ray burst science software preparation. Drs. Gehrels, Ormes, Ritz and Thompson are members of the LAT Senior Scientist Advisory Committee, which is chaired by Dr. Gehrels. Dr. Ritz is the LAT Instrument Scientist and is part of the core LAT management team. Dr. Thompson is a LAT team member of the GLAST Science Working Group, and is also the LAT team multiwavelength coordinator. Drs. Harding, Hunter, Moskalenko, and Stecker are Associate Investigators on the LAT team, working on the preparation for science analysis. David Wren and Luis Reyes are University of Maryland Ph.D. students working on GLAST performance evaluation, onboard event identification, and science preparation.

A number of important mission-level science and leadership functions are also provided by Goddard. The project scientist is Dr. Ritz, with Drs. Gehrels and McEnery serving as Deputy Project Scientist and Mission Scientist, respectively. The GLAST Science Support Center (GSSC) is located at Goddard, and is led by Dr. Norris. Drs. Band, Bonnell, Jim Chiang (UMBC), Valerie Connaughton (UAH), Corbet, Davis, Hirayama, Petry, Schaefer and Stephens are Ph.D. scientists on the GSSC staff. GSSC personnel are preparing to support the large number of expected GLAST Guest Observers and are collaborating with the instrument teams on the design, development and testing of science analysis tools. LHEA GLAST Education and Public Outreach activities, under the leadership of Prof. L. Cominsky of Sonoma State U., by Drs. Gehrels, Bonnell, and Lochner include teacher workshops, museum exhibits, posters, videos and web pages.

4.5 EXIST

The Energetic X-ray Imaging Survey Telescope (EXIST) is a NASA mission to survey the gamma-ray sky in the 5-600 keV energy band. It is being studied as an Einstein Probe in the NASA Structure and Evolution of the Universe division Beyond Einstein program. This year EXIST was selected and funded for a two-year concept study. The theme of the mission is surveying black holes of all size scales. Objectives include the following: 1) determine the population and physical nature of obscured Seyfert II AGN; 2) detect gamma-ray bursts out to redshifts of 20 and use them to study the early Universe; and 3) study stellar-mass and intermediate-mass black holes in the Galaxy. Prof. Jonathan Grindlay (Harvard) is the EXIST Principal Investigator. At Goddard, Dr. Gehrels is the Study Scientist and Drs. Barthelmy, Mushotzky, Parsons and Tueller are team members.

4.6 Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA)

Sensitive measurements of the antiproton and positron components of the cosmic radiation can constrain models of the Dark Matter that pervades the universe. The PAMELA instrument in a high-inclination orbit will measure these spectra from 50 MeV to over 100 GeV using a magnetic-rigidity spectrometer with precision silicon tracking combined with a time-of-flight (TOF) system, a transition-radiation detector, and a silicon-imaging calorimeter to fully identify charged particles. PAMELA is under construction for flight in 2005 by a collaboration that includes Italy, the US, Germany, Sweden, and Russia, headed by Prof. P. Picozza of INFN Roma II (Italy). Dr. Mitchell leads the US work on PAMELA and serves as a member of the International Program Committee. Dr. Streitmatter is a member of the Scientific Committee and Dr. Moiseev is involved in instrument modeling. PAMELA was tested at the CERN SPS accelerator in September 2003 and final preparations for flight are nearing completion. PAMELA will be shipped to Russia late in 2004 for integration with the spacecraft.

4.7 Solar-Terrestrial Relations Observatory (STEREO)

Dr. von Rosenvinge is a Co-investigator for the IMPACT investigation of the STEREO mission. Dr. J. Luhmann (U. of

California, Berkeley) is the Principal Investigator. Duplicate instruments on each of two spacecraft, one leading the Earth and one trailing the Earth, will image Coronal Mass Ejections from the Sun heading towards the Earth. This will permit stereo images to be constructed to investigate the three-dimensional structure of Coronal Mass Ejections. The IMPACT investigation will provide corresponding *in situ* particle measurements. The two STEREO spacecraft are being built by the Applied Physics Laboratory of Johns Hopkins U. for launch by a single rocket in early 2006.

4.8 Astro-E2

The Astro-E2 mission is being developed jointly by NASA/Goddard and the Aerospace Exploration Agency/ Institute of Space and Astronautical Science in Japan to provide astrophysicists with high-resolution, high-sensitivity X-ray spectroscopy over a wide range of photon energies. The core instrument, the high-resolution X-Ray Spectrometer (XRS) is based on the X-ray microcalorimeter, a device that thermally detects individual X-ray photons and measures their energies with very high precision and sensitivity. The XRS is a cryogenic instrument and the cooling system has been designed to last at least 2.4 years in orbit.

The microcalorimeter array consists of 32 pixels, each with a size of 625 microns, or about 30 arcsec. One of the pixels is out of the field of view of the X-ray mirror and will be illuminated by a ^{55}Fe X-ray source to provide constant gain calibration data. The energy resolution of the array is about 6 eV and the overall effective area of the instrument is about 150 cm^2 over much of the 0.3-10 keV band. This will enable powerful diagnostics of high-energy processes from measurements of L- and K-shell atomic transitions through Ni, and velocity information, to be determined with high precision.

The other instruments on Astro-E2 include a set of four CCD cameras (developed jointly by MIT and various institutions in Japan) and a combination photo-diode/scintillator detector system (developed primarily by the University of Tokyo and ISAS) that will extend the band pass up to nearly 700 keV. A significant feature of Astro-E2 is that all of the instruments are coaligned and operated simultaneously. The observatory will be launched into low earth orbit on a Japanese M-V rocket in early 2005.

Major accomplishments were achieved this year as all of the flight hardware for the XRS was completed, tested, calibrated, and shipped to Japan. Members of the XRS instrument team within the LHEA include Drs. Boyce, Brown, Cottam, Kelley, Kilbourne, and Porter, and they were involved in all aspects of these activities. Drs. Porter, Brown and Cottam finalized preparations for the calibration work at Goddard, which took place in December 2003 and again in February and March 2004, and supported extensively by all members of the team. This work produced the most detailed and comprehensive data on the performance of an X-ray microcalorimeter ever obtained. Drs. Kelley and Porter accompanied the XRS detector system and helium cryostat to Japan for integration into the Neon dewar in March 2004. They were also involved in the delivery and installation of the aperture assembly and dewar pump down in June 2004.

The XRS and XIS instruments sit at the focus of large collecting area, lightweight X-ray mirrors developed in the LHEA under the direction of mirror principal investigator Dr. Serlemitsos. Drs. Serlemitsos, Chan and Soong have successfully delivered all five of the X-ray mirror assemblies to Japan.

The Astro-E2 Guest Observer program (Cycle 1) was released as a part of the Research Opportunities in Space Science -- 2004 NASA Research Announcement in January 2004. Consequently, the major focus of the Astro-E2 Guest Observer Facility (GOF) has been to prepare documentation and software for proposal preparation and submission.

In collaboration with ISAS/JAXA, members of the GOF, including Drs. Angelini, Arnaud, Ebisawa, Harrus, Mukai, and Smith, produced the Technical Description of the Observatory. This includes verification, documentation, and dissemination of the response matrix and related tools for simulations. They also prepared the Astro-E2 version of the Remote Proposal Submission forms and assisted the community in the process of proposal preparation. In addition, the GOF is continuing its work on data processing and calibration files. Dr. Randall Smith arrived from SAO to join the Astro-E2 team. He will support the GOF activities and participate in the scientific observations and analysis.

Dr. Kelley is the Principal Investigator for the US participation in the mission and the XRS instrument and Dr. White is the NASA Project Scientist.

4.9 The Dark Universe Observatory (DUO)

DUO was selected in October 2003 by NASA as one of five Small Explorer (SMEX) missions for a concept study. The objective of DUO is to measure with high precision the Dark Energy equation of state parameter (w) and other key cosmological parameters using the mass power spectrum and the distribution with redshift of clusters of galaxies at redshifts up to 1.2. Eight-thousand-square degrees of Sloan Digital Sky Survey (SDSS) region and a 150-square degree southern region are surveyed in X-rays to locate the clusters. Redshift information for 95 percent of the clusters in the Sloan region are available in the SDSS; redshifts for the remainder and the southern field are obtained from dedicated observations. Dr. Richard Griffiths of Carnegie Mellon University is the Principal Investigator. Key participants include MPE, the University of Hawaii, the University of Illinois, and Sonoma State University. The GSFC role includes project management, science operations, the X-ray mirror, and participation on the science team. GSFC participants are Deputy PI R. Petre, co-investigators R. Mushotzky, K. Jahoda, N. White, and collaborators F. Marshall, M. Corcoran, and K. Arnaud. The concept study was completed in June 2004; NASA will select two of the five missions in late 2004.

5. INSTRUMENTATION, SUB-ORBITAL AND NON-FLIGHT PROGRAMS

5.1 Trans-Iron Galactic Element Recorder (TIGER)

The Trans-Iron Galactic Element Recorder (TIGER) is a balloon-borne spectrometer designed to measure the cosmic ray abundances of elements heavier than iron. From Goddard, Dr. Louis Barbier (GSFC Lead Co-I), Dr. Georgia de Nolfo (NRC), Dr. John Mitchell, and Dr. Robert Streitmatter are participants. Goddard supports the Cherenkov detector subsystems in the TIGER instrument. Dr. W. Robert Binns from Washington University (St. Louis) is the PI, and the team also includes Dr. Marty Israel, Jason Link, and Lauren Scott (Wash. U.), Dr. Sven Geier, Dr. Richard Mewaldt, Dr. Stephen Schindler and Dr. Edward Stone (Caltech), Dr. Jake Waddington (U. of Minnesota), and Dr. Eric Christian (NASA HQ).

After its record-breaking balloon flight from Antarctica during December 2001 and January 2002, becoming the first payload to circumnavigate Antarctica twice and make a record-breaking 31.5 days at the top of the atmosphere, TIGER was returned to the US and refurbished. It was shipped back to Antarctica for another flight in December of 2003. The instrument was launched on December 16, 2003 and cut down on January 4, 2004—a very successful 18-day flight. The instrument made 1.5 revolutions of the South Pole and came down in a fairly remote area. Recovery operations were minimal (returning a data disk) and the instrument is sitting on the ice awaiting a future recovery opportunity.

A paper was presented at the COSPAR conference in Paris in early July 2004, describing the instrument, the fight, and a proposed follow-on version, named SUPER-Tiger.

5.2 Balloon-borne Experiment with a Superconducting Spectrometer (BESS)

BESS was developed to make high-statistics measurements of cosmic ray antimatter and has recorded over 90 percent of all measured cosmic ray antiprotons. Prof. A. Yamamoto of the High Energy Accelerator Research Organization (KEK) leads the BESS project in Japan, involving four institutions and Dr. Mitchell leads the US effort at GSFC and the University of Maryland. BESS combines the largest geometric acceptance of any balloon-borne magnetic-rigidity spectrometer ($0.3 m^2 sr$) with powerful particle identification, using an advanced superconducting magnet and precision time-of-flight (TOF), Cherenkov, and tracking systems. It has had nine successful balloon flights since 1993, measuring the spectra of cosmic ray antiprotons and light nuclei, and performing a sensitive search for antihelium. A new BESS-Polar instrument has been developed for an Antarctic flight program beginning in 2004/2005 to measure antiprotons with unprecedented statistical precision from 100 MeV to 4.2 GeV, and extend measurements of cosmic ray spectra to energies of 500 GeV. Drs. Hams, Mitchell, Moiseev, Ormes, Sasaki, and Streitmatter are working on analysis and interpretation of current BESS data and on the development of instrumentation for BESS-Polar. Dr. Sasaki is responsible for the BESS-Polar trigger and digital electronics, Dr. Hams is responsible for the Aerogel Cherenkov Counter, Dr. Mitchell is responsible for the TOF system, and Dr. Streitmatter is responsible for thermal analysis and control. A short test flight of BESS-Polar from Palestine, TX, in September 2003 was very successful. Full integration at GSFC and Palestine for the Antarctic flight has been completed. BESS-Polar will be shipped to Antarctica in October 2004 for a flight in December 2004 or January 2005.

5.3 Nightglow

In December 2002 NIGHTGLOW was shipped to Alice Springs, Australia and prepared for a second attempt at an ultra-long-duration balloon (ULDB) flight around the world. (Dr. Louis Barbier, PI) After integration there was a 2.5-month delay in waiting for proper launch conditions. A beautiful launch was achieved on March 17th, 2003 at approximately 8:38 AM local time. During the ascent phase of the mission, an anomaly was seen in the balloon shape and internal pressure. After repeated attempts to correct the situation, it was determined that the flight should be terminated. After a trip of less than 300 miles from the launch site, the instrument was cut down and landed in the Australian Outback (in a shallow lake!). Recovery was difficult, taking just over one week and some damage occur to the payload, both during the landing and on the recovery trip.

Currently, the instrument is back at Goddard for repairs and upgrades in hope of a third launch attempt in 2005. The upgrades include re-aluminizing the mirrors, reducing the telescopes weight by employing carbon-fiber epoxy shrouds, a modified landing leg design, and new LabView based GSE software, with the capability for remote operations.

On the bright side, the design, fabrication, and integration of the LIDAR system was successful, giving NIGHTGLOW the capability to monitor cloud cover as well as measure the near ultra-violet emissions in the atmosphere.

Ultra-high energy cosmic ray particles, with energies greater than 10^{20} eV, are detected by the nitrogen fluorescence they produce in the atmosphere. Nightglow helps to monitor the background light against which that signal would be seen by an orbiting instrument, such as EUSO or OWL.

5.4 International Focusing Optics Collaboration for μ Crab Sensitivity (InFOCμS)

The InFOCμS team has flown the first complete hard X-ray, multilayer grazing-incidence telescope with a CdZnTe pixel focal plane and successfully imaged Cyg X-1. The team is preparing to fly the instrument again in late summer 2004 with an improved pointing system to observe a number of hard X-ray targets including Cassiopeia A and several AGN. This breakthrough combination of technologies yields order of magnitude improvements in sensitivity and angular resolution with high-resolution spectroscopy. The first InFOCμS mirror is 8 m in focal length and 40 cm in diameter, with 2040 fully multilayered reflectors and an effective area of 40 cm2 at 30 keV with a measured HPD PSF of 2.6 arcmin. The measured, in- flight, 3-sigma sensitivity (4.6×10^{-6} ph cm^{-2} s^{-1} keV^{-1} = 600μCrab in 8 hours in the 20 - 40 keV band) of this initial, one-telescope configuration is already capable of significant new scientific observations. Crucial to this sensitivity is the low background achieved by the concentration of focusing optics and background suppression with heavy CsI shielding. The InFOCμS focal plane has the lowest reported CdZnTe background of 2.4×10^{-4}

cnts cm^{-2} s^{-1} keV^{-1}. In a future configuration we expect to be able to map the ^{44} Ti in Cas-A and make a definitive measurement of ^{44} Ti from SN1987A. InFOCμS will also be a superb instrument to follow-up the Swift/BAT hard X-ray survey, especially the many newly discovered, highly obscured, nearby AGN. This international collaboration (Drs. Tueller, Barbier, Barthelmy, Chan, Gehrels, Krimm, Okajima, Parker, Parsons, Petre, Serlemitsos, Soong, Stahle, and White at GSFC/LHEA, Sachi Babu and Brad Parker (GSFC/AETD; Dr. H. Kunieda at ISAS in Japan, Drs. A. Furuzawa, Y. Ogasaka, K. Tamura Y. Tawara, and K. Yamashita at Nagoya U.; B. Barber, E. Dereniak, E. Young at U. of Arizona) includes world leaders in the development of foil mirrors, multicoated optics, segmented CdZnTe detectors, and balloon payloads with the experience and resources necessary to successfully exploit these promising new technologies for the future Constellation-X mission.

5.5 Gamma Ray Burst Coordinates Network (GCN)

The GRB Coordinates Network (GCN), operated by Dr. Scott Barthelmy of GSFC, continues to deliver locations of GRBs to instruments and observers throughout a distribution of delays, from only seconds after the GRB onset with preliminary localizations (while most events are still in progress), to hours or days later, with refined data. These alerts make possible all multi-band GRB follow-up observations, simultaneous and evolving. This was routine during the GRO-BATSE years and it has resumed with the HETE mission. A primary goal of the GCN was realized with the optical detection of the burst counterpart for GRB990123 by the ROTSE instrument during the several-second duration of this GRB. The GCN system is entirely automatic and is all encompassing: it collects all known information on GRB locations from all sources into a single point and transmits that information to all sites, globally. Thus, each observatory or researcher needs to develop and maintain only one connection for all GRB needs. No humans are involved within the GCN system proper, so the delays are minimized to little over 1 second for HETE events and to several to several tens of seconds delay (after receipt of information) from sources such as RXTE. Currently, the GCN system distributes Notices to 235 locations involving over 400 researchers. These include 65 locations with 80 instruments: 34 optical, 12 radio, 16 gamma ray, 7 X-ray, 3 gravity wave and 3 neutrino. Also, these include 12 fully automated or robotic instruments. The other recipients are researchers or teams associated with telescopes or activities such as cross-instrument correlation operations. As of Aug 31, 2004, 2684 Circulars have been distributed.

5.6 Three-dimensional Track Imaging Micro-Well Detectors for Gamma-Ray Telescopes

Three-dimensional track imaging gas micro-well detectors are being developed in the LHEA (Dr. Hunter) for Compton scattering and pair-production gamma-ray telescopes with high polarization sensitivity, and for fast neutron imaging for planetary exploration. The micro-well detectors, which exploit narrow-gap electrodes, rather than thin anodes, to achieve gas amplification, are a demonstrated, mechanically simple means of high-resolution (~50 μm) imaging over large areas. We (with Drs. Deines-Jones and Black) have demonstrated that this detector geometry offers: 1) Sub-pixel resolution: detectors with 400 micron pixel spacing having 85 μm resolution. 2) Stable operation: gas gains of 30,000 are routine. 3) Mechanical robustness: uses flexible printed circuit technology. 4) Typical proportional counter energy resolution: 20% FWHM at 6 keV.

The three-dimensional track imagers for our gamma ray and fast neutron telescopes consist of micro-well detectors with two-dimensional crossed-strip readout augmented with time resolved measurement of the ionization charge arrival to provide the third coordinate. Negative ion drift is utilized to reduce the velocity of the ionization charge and to reduce the sampling rate of transient digitizers on each anode and cathode. We are working toward an ASIC implementation of a multi-channel transient digitizer.

The current goals of this high priority work, motivated by the requirements of the medium-energy (0.5-30 MeV) Advanced Compton Telescope (ACT) mission, are to fabricate 16 cm $\times$ 16 cm three-dimensional track imaging detectors, assemble these detectors into a prototype medium-energy (Compton scatter) gamma-ray telescope, and test this telescope at an accelerator in the next 2-3 years. The goals of the ACT mission are to study the emission from SNRs, pulsars, black holes, and the EGRET unidentified gamma-ray sources with high polarization sensitivity and sufficient energy resolution to study emission lines.

We are also developing a concept for a high-energy (~50 MeV-100 GeV, i.e. pair production) Advanced Pair Telescope (APT). This instrument would permit high angular resolution studies of the Galactic diffuse emission in the Milky Way as well as other nearby galaxies, high-energy pulsars, active galactic nuclei, supernova remnants, and gamma-ray bursts. The high spatial resolution and nearly continuous low-density gas volume three-dimensional micro-well track imager permits many thousands of position measurements per radiation length. This allows the electron and positron directions to be accurately determined before multiple scattering masks their original directions, providing arc minute angular resolution and polarization sensitivity. We have performed GEANT4 simulations to estimate the polarization sensitivity of simple telescope geometries. We will extend these simulations and use the results to optimize the design of this telescope.

5.7 The High Energy Astrophysics Science Archive Research Center (HEASARC)

HEASARC is one of NASA's wavelength-specific science archive research centers and is operated by LHEA in partnership with the Harvard-Smithsonian Center for Astrophysics (CFA). The Director of the HEASARC is Dr. White, the Associate Director is Dr. Roger Brissenden (CFA), the Chief Archive Scientist is Dr. McGlynn, and the Archive Scientists are Drs. Angelini, Corcoran, Drake, Lochner, Arnaud and Pence. The HEASARC provides the astrophysics community with access to the data archives from both past and current extreme-ultraviolet, X-ray, and gamma-ray missions. In order to maximize the scientific utilization of this archive, the HEASARC has defined formats and file types for high-energy astronomy data sets, and also has written both a general-purpose FITS file manipulation library (FITSIO) and multi-mission data analysis software (HEAsoft). In addition the HEASARC provides a suite of Web utilities that are appropriate both for high-energy observation planning and/or data analysis, e.g., tools for the simulation of X-ray spectra (WebSpec) and for the calculation of the diffuse X-ray background level in any direction, and also for more general astronomical purposes, e.g., tools to convert sky coordinates, dates, and energies to and from the various alternative systems which are in common usage.

Highlights from the past 12 months of HEASARC operations include:

(i) the evaluation of the HEASARC by NASA's Astronomy and Physics Mission Operations and Data Analysis Programs 'Senior Review': the report is available at http://spacescience.nasa.gov/admin/divisions/sz/SenRev04.pdf;

(ii) the total volume of archival high-energy data growing from 3.0 to 3.5 Terabytes (TB), which includes 1.2 TB of RossiXTE data, 0.5 TB each of XMM-Newton and BeppoSAX data, 0.4 TB of ASCA data, 0.2 TB of Compton GRO data, and 0.7 TB of data from 18 other gamma-ray, X-ray, and extreme-ultraviolet astronomy missions;

(iii) record amounts of data, software, images, and webpages downloaded by HEASARC users: 5.9 TB via anonymous ftp and/or the ftp server, and 2.0 TB via the Web (http) server;

(iv) a record number (4,527,000) of queries made using the HEASARC's Web-based multi-mission database and catalog service, Browse, an increase of 77% compared to the previous 12-month period;

(v) continued heavy usage of the HEASARC's SkyView utility (a Web-based tool to display images of selected portions of the sky in various projections and in any of a wide range of wavelengths), with the number of generated images close to 1.5 million;

(vi) the creation of 10,000 more entries in the bibliographic code/dataset identification correlation tables for HEASARC archival datasets: these links allow users of the NASA Astrophysics Data System (ADS) to jump immediately from the ADS bibliographic record of a paper to the HEASARC high-energy datasets which were analyzed in that paper (essentially all papers which have presented ROSAT, ASCA, and XMM-Newton data analyses now have the ADS/HEASARC link in place);

(vii) the continuation of an AISRP-funded effort called ClassX to develop a prototype National Virtual Observatory (NVO) utility, namely a source classifier that will use a range of distributed, multi-wavelength datasets so as to allow users to classify samples of X-ray sources based on a large number of scientific criteria; and

(viii) the development of the first National Virtual Observatory (NVO) tool, the DataScope Data Inventory Service, which allows users to search the holdings of 12 different archives (including radio, IR and optical data sets as well as high-energy) in a single query.

5.8 High Resolution Detector Development

The X-ray Astrophysics Branch is developing X-ray microcalorimeters for high resolution X-ray spectroscopy. The specific areas of development include low noise, high sensitivity thermometers, schemes for fabricating large arrays with high filling factor, and X-ray thermalizing absorbers that can be directly incorporated into the device fabrication process. The instrument electronics that will be required for large arrays of microcalorimeters are also being developed. Present members of the LHEA microcalorimeter team include Drs. Bandler, Boyce, Brown, Cottam, Figueroa-Feliciano, Finkbeiner, Kelley, Porter, Saab and Kilbourne. During the last year, Dr. Mark Lindeman left our group to accept a research position with Prof. Dan McCammon at the University of Wisconsin.

Work is continuing on improving X-ray microcalorimeters with ion-implanted Si thermometers and superconducting transition edge thermometers. In the past year, we have spent considerable time characterizing the 32-pixel array developed for the Astro-E2/XRS instrument. This work has demonstrated a line spread function that is extremely Gaussian with a FWHM of about 6 eV. In separate tests, we have also tested devices with smaller absorber size in an effort to see what the highest resolution that can be obtained is. Using absorbers that are 400×400 microns, we have consistently obtained a resolution of about 4 eV. The central focus of our work in this area now is in improving arrays especially designed for low energy work for upgrading our sounding rocket payload. This instrument is a joint effort between our group and Prof. D. McCammon at the U. Wisconsin to study the X-ray emission from the diffuse X-ray background below about 1 keV.

In the past year, we have produced the first functional 8×8 TES devices with pixels designed to meet the Constellation-X requirements for size, quantum efficiency, etc. The results are extremely good for this stage of the program (e.g., 5-7 eV.) We have also fabricated and tested TES devices with a variety of thermistor geometries with the goal of studying the affect this has on TES noise. Our group has also initiated work on magnetic calorimeters. These devices use a paramagnetic material in a magnetic field to measure temperature changes as variations in magnetization. Work on these and TES microcalorimeters will continue in parallel to achieve the highest spectral resolution and establish which is the most reliable and robust for future flight applications.

5.9 Gas Micro-pattern Detectors

Imaging micro-well proportional counters and related gas micro-pattern devices are being developed in the LHEA by Drs. Black, Deines-Jones, Jahoda, and Swank for electron tracking in X-ray polarimeters large-format X-ray imaging. Gas micro-pattern detectors exploit narrow-gap electrodes, rather than thin anodes, to achieve gas amplification and are capable of diffusion limited imaging.

The current highest priority is to use micro-pattern detectors to measure X-ray polarization through measurements of the direction of the initial photo-electron, which carries information about the polarization of the incident X-ray.

Work in the LHEA is concentrated on fabrication techniques and readout electronics that are well matched to the estimated requirements of a polarimetry detector or readily extensible to large areas (thousands of square centimeters). Sensitive polarimetry requires a suitable combination of long photo-electron tracks (which argues for low gas pressure), high quantum efficiency (which argues for high pressure or deep chambers), and minimal blurring due to transverse diffusion in the drift region (which argues for thin detectors and carefully chosen drift fields). Polarimeter requirements are being studied by simulation in collaboration with the detector group at INFN-Pisa headed by Dr. R. Bellazzini and a group in Rome headed by Prof. E. Costa. The LHEA effort has also identified achievable laboratory standards for creating polarized X-rays and is progressing towards validating the simulation effort.

A polarimeter consists of a sensitive volume, an amplification stage, and a pixelized readout. We are building polarimeters that will use pixelized readout devices developed by Dr. Bellazzini's group. Previous laboratory demonstrations of polarimetry have used a Gas Electron Multiplier (GEM) as the multiplication stage. Our effort has been exploring the suitability of various GEM detectors or related geometries and on the possible beneficial effects in diffusion reduction by adding electro-negative gasses to the sensitive region. GEM detectors create multiplication by arranging two electrodes on either side of a perforated dielectric. Multiplication takes places in the high field region within the holes. The GEM must be arranged so that electrons in the sense region are efficiently collected by the GEM, and there must be a transfer field to transport the multiplied signal to a readout plane. We are exploring the use of parallel etched stainless steel grids to replace the GEM, and create a clean all metal detector.

The possibility of a large reduction in the transverse diffusion via the admixture of an electro-negative gas relies on the idea that the ionization created in the sensitive volume will be quickly attached to the admixture molecules (CS2, for instance) and transported to the multiplication region as a negatively charged (and massive) molecule. Once in the multiplication region, the electron must be stripped off in order to initiate a traditional avalanche multiplication. Initial results are promising and investigation is continuing.

Another potential application of micro-pattern devices is as microwell detectors in the focal plane of the Lobster-ISS all sky monitor (an ESA led project in extended phase A, PI Prof. G. Fraser of Leicester) We have previously demonstrated that micro-well detectors are a simple and inexpensive means of high-resolution (few hundred micron) imaging over large areas suitable for Lobster. With Lobster-ISS in mind we have previously demonstrated that micro-wells offer: 1) Subpixel resolution: detectors with 400 micron pixel spacing having 85 micron resolution. 2) Stable operation: gas gains of 30,000 are routine. 3) Mechanical robustness: uses flexible printed circuit technology. 4) Typical proportional counter energy resolution: 20% FWHM at 6 keV. Detector development for this application has been relatively inactive while scheduling and programatic issues with the ISS are being sorted out.

5.10 Laboratory Astrophysics

A NASA/GSFC microcalorimeter array and portable laboratory adiabatic demagnetization refrigerator, based on Astro-E XRS technology, has continued to operate as part of the Laboratory Astrophysics program centered at Lawrence Livermore National Laboratory's electron beam ion trap EBIT-I. EBIT-I operates at electron densities of $\sim 10^{12}$ cm^{-3} and in the 10^6-10^8 K temperature range, parameters similar to a plethora of astrophysical plasmas. The resulting X-ray emission can be viewed simultaneously through several ports using crystal and grating spectrometers, high-purity solid state detectors, and the EBIT/XRS calorimeter. The X-ray microcalorimeter has high spectral resolution coupled with high quantum efficiency over a large bandwidth making it well suited to the study of weak atomic processes.

In October of 2003, EBIT/XRS array was replaced by an Astro-E2 type calorimeter. The resolution of the array is $\sim$ 6 eV representing nearly a factor of two improvement in resolving power. In addition, the analog electronics have been replaced and work is presently being completed on replacing the hardware digital processor to a fully operational software digital processor.

The EBIT/XRS has continued to be used to solve problems facing the accurate interpretation of non-terrestrial X-ray spectra. In particular we have studied the absolute excitation cross sections of a variety of of Fe L-shell transitions, the unique X-ray signatures of charge-exchange recombination, lifetimes of atomic levels, and X-ray emission from neon-like nickel. In addition, we have found that, although not specifically designed for it, the EBIT/XRS can be operated as a high-resolution gamma-ray detector extending our measurements to include nuclear transitions.

Measured excitation cross sections provide one of the most stringent tests of atomic and spectral modeling packages. At EBIT-I, absolute excitation cross sections of Fe L-shell X-ray transitions are measured by normalizing the photon emission from direct excitation to the much weaker emission from radiative recombination. Owing to its large bandwidth, high-resolving power, and stable gain, the EBIT/XRS is perfectly suited to this purpose. We have measured the absolute cross sections of Fe L-shell transition from several Fe ions including Fe XVII, and Fe XXI-XXIV. In many cases, agreement was found between theory and experiment. In the case of Fe XVII, however, the cross section of the resonance line at 15 angstroms was found to differ from theory by as much as 50%. This result uncovered the source of the long standing disagreement between calculated relative intensities involving the resonance line and those measured from non-terrestrial plasmas.

X-ray emission from charge exchange recombination is by far the most likely process responsible for X-ray emission from cometary atmospheres. X-ray emission from charge exchange between relatively slow moving ions and cometary neutral is regularly simulated in the lab with EBIT-I and its X-ray emission is recorded with the EBIT/XRS.

We are cataloguing the X-ray signatures of several astrophysically relevant ion-neutral interactions in anticipation of observations of cometary atmospheres and the galactic ridge, two experiments are planned for Astro-E2.

Lifetimes of atomic transition are one of the most important parameters necessary for reliably interpreting astrophysical spectra. Taking advantage of the large collecting area and the submillisecond timing resolution of the EBIT/XRS, we have measured the lifetimes of several X-ray transitions in highly-charged neon. Results of these studies show that contemporary atomic models correctly predict the lifetimes of lower multipole transitions, however, for higher multipoles such as magnetic octupoles, the models overestimate the lifetimes by $20-40\%$.

After iron, nickel is one of the most abundant high-Z elements in astrophysical sources. To provide benchmarks for spectral models, we have used the EBIT/XRS in conjunction with a high-resolution grating spectrometer to measure the relative intensities of neon-like Ni XIX. The results demonstrate the problems with astrophysical modeling packages are not limited to iron emission, but persist along the neon-like isoelectronic sequence. Specifically, the relative line strength of the 2p-3s to 2p-3d lines in Ni XIX is underestimated by theory and the resonance 2p-3d $^1P_1$-$^1S_0$ to $^1P_1$-$^1S_0$ intercombination line is underestimated. These results were presented in the *Astrophysical Journal*.

In anticipation of the launch of Astro-E2, several measurements of Fe K-shell emission are taking place. These included both heliumlike Fe XXV and hydrogenic Fe XXVI. These measurements were done using the Maxwellian simulator mode unique to the LLNL EBIT facility. These results will be used to calibrate the temperature sensitivity of the relative intensity of the dielectronic satellite to resonance lines in hydrogenic Fe and the G=(x+y+z)/w line ratio in helium-like Fe. Experimental standards such as these will prove useful in the interpretation of spectra provided by the Astro-E2/XRS.

In the next year, a permanent EBIT Calorimeter Spectrometer (ECS) built at NASA/GSFC will be installed at the LLNL EBIT-I. The ECS will be designed for minimum servicing and high operational duty cycle, with integration times of several days. Because this array, already operational at LLNL, is a near exact replica of the flight XRS array on Astro-E2, it may be used for extended calibration and testing during the entire Astro-E2 mission lifetime.

This work is being carried out in collaboration with Drs. Peter Beiersdorfer, and Hui Chen at LLNL, and Steve Kahn and Ming Feng Gu at Stanford University. LHEA's contribution to this work is being carried out by Drs. Boyce, Brown, Kelley, Porter, and Kilbourne.

Drs. Gendreau, Arzoumanian and Mr. Moya are constructing a 600 meter long X-ray Interferometry testbed. This testbed is capable of testing interferometry concepts involving baselines up to 10 cm for X-ray energies from <0.5 to 10 keV. Concepts of enabling technologies for NASA's Black Hole Imager (BHI) mission will be tested in this new facility. First light is expected in October 2004.

Drs. Gendreau, Finkbeiner, and Arzoumanian are collaborating with Dr. K. Schwab (UMCP) to develop a superfluid gyroscope capable of rotational rate sensitivities approaching 1 microarcsecond/s/sqrt(Hz). This device will possibly play a key role in the BHI mission as well as other sub milliarcsecond imaging missions.

Drs. Gendreau and Arzoumanian with Drs. Trombka and Floyd (GSFC/LEP), are developing a multiwavelength X-ray diffractometer for the high-speed identification of samples found on planetary surfaces. The diffractometer will ultimately be a low power/low mass instrument that requires no sample preparation.

Drs. Jahoda, Deines-Jones and Black, with Drs. R. Street and S. Ready (Palo Alto Research Center) published a study on high sensitivity X-ray polarimetry with amorphous-silicon active-matrix pixel-proportional counters.

5.11 Optics

LHEA continues to develop thin foil mirrors for high-throughput X-ray imaging missions. Emphases have been on the circularly nested Wolter-I construction and its derivative. Research, aiming to produce high throughput and high resolving power, include improvement of reflector axial figure, strength and material of substrates, assembly and mounting mechanisms; and, for future hard X-ray, long focal length systems, multilayer coating for hard X-ray reflection. Projects involving LHEA mirrors are: Astro-E2, Constellation-X and InFOCμS. Current research scientists include Drs. Chan, Lehan, Misaki, Okajima, Serlemitsos, Soong and Zhang. Fabrication of reflectors and assembly of 5 X-ray telescopes for Astro-E2 are completed. They are delivered to Japan, from where Astro-E2 will be launched in 2005. These telescopes are light-weighted (< 20 kg each), have high X-ray collecting efficiency ($\sim$ 340 cm^2 each at 4.5 keV) and have resolving power better than 2″ in half-power diameter. Drs. Serlemitsos, Soong, Chan, Okajima and Misaki led the effort in the completion of these mirrors.

For imaging in the hard X-ray, the balloon project InFOCμS demonstrated in a 2001 flight the imaging capability, up to 40 keV, at $\sim$ 2 arc-minute. A second flight with a modified telescope is underway. Dr. Okajima modeled the hard X-ray response for the multilayerd mirror surfaces and studied the mirror alignment with the gondola system. Several new mirror-making processes are being pursued.

Drs. Petre and Zhang continued to lead X-ray mirror development for Constellation-X. The optics concept under study involves precise forming of sheets of glass into segments that get assembled into a modular, highly nested grazing incidence mirror with 1.6 m diameter and 10 m focal length. Research concentrated on the glass forming process, which is done by slumping glass over precisely shaped mandrels at high temperature. The first mandrels figured to a Wolter geometry were fabricated; previous forming mandrels had only a conical approximation. A new release layer for the mandrels was also developed. Incorporation of these two modifications have led to substantially improved reflector substrates, which for the first time have sufficient quality to meet the stringent Constellation-X performance requirement.

5.12 Education and Public Outreach

Under the direction of Dr. Lochner, the Laboratory for High Energy Astrophysics continues its outstanding program in education and public outreach through the continuing development of new curriculum support materials, presenting workshops at national and regional educator meetings, and working within the NASA OSS Education Support Network of Education Forums and Broker/Facilitators.

We continue to develop the ‘‘Imagine the Universe!’’ (http://imagine.gsfc.nasa.gov/) Website to bring the Lab’s science to the education community. We completed a set of ‘‘Cool Facts’’ for each of the science topics, and continued our series of profiles of Lab scientists. We also added a new article about the upcoming Swift mission. Christopher Wanjek (SP Systems) writes news of discoveries from Chandra, XMM-Newton, RXTE and other missions which are posted on the site monthly.

In January 2004, we prepared and released the 8th edition of the ‘‘Imagine the Universe!’’ CD-ROM, containing a capture of the Imagine Website, as well as StarChild and Astronomy Picture of the Day for the year 2003. This CD-ROM is distributed free upon request, at teacher conferences, and via NASA CORE. We expect to distribute 20,000 of the CDs during the course of the year.

The LHEA outreach group continues to present teacher workshops at a variety of educator meetings, including the National Science Teacher’s Association National and Area meetings, the Science Teachers of New York State annual conference, and numerous smaller educator workshops locally and at NASA/GSFC. Staff exhibit booths and present workshops which train teachers to use our materials in their classrooms. Our workshops topics now include using our CD-ROM, using the StarChild Web site, the ‘‘Hidden Lives of Galaxies,’’ ‘‘Black Holes in a Different Light,’’ ‘‘Life Cycles of Stars’’ and ‘‘What is Your Cosmic Connection to the Elements?’’ These workshop presentations are posted on the Imagine Website for teachers to use with their classes. We directly reach over 400 teachers each year with these workshops. By providing our materials to other workshop providers, we reach an additional 3500 teachers each year.

Drs. Lochner and Pence continue the development of the education interface for the Hera software. Now called ‘‘Student Hera,’’ this interface enables high school students to analyze X-ray timing data using a subset of the FTOOLS software and data from the RXTE ASM. The system has now been adapted for college level Astronomy 101 labs by Dr. Beth Hufnagel (Anne Arundel Community College). These versions have been extensively tested by high school and community college students.

Dr. Lochner and Dr. James Thieman (NASA/GSFC) collaborated with the Physics Teacher Resource Agents, a ‘‘train the trainers’’ program operated by the American Association of Physics Teachers, to develop a workshop on the EM spectrum using NASA materials.

With Dr. Ann Hornschemeier (Johns Hopkins Univ.), Dr. Lochner assisted in developing a program and materials for Girl Scouts to learn about origin of the elements, supernovae, and black holes.

We also continue to work closely with the NASA OSS education effort by supporting the Broker/Facilitators with materials for use in their workshops, and by supporting the SEU Education Forum (Dr. Roy Gould, SAO) through staffing of exhibit booths at national meetings, and working with them on a variety of education projects. In April we participated in presenting the Forum’s Short Course on ‘‘Modeling the Universe’’ at the NSTA national convention.

Coordinating with Dr. Lochner, cosmic ray education and public outreach continued under the direction of Ms. Beth Jacob (SP Systems). Drs. Thompson, Barbier, Mukai, Harrus, and Dr. Eric Christian (NASA HQ) gave presentations on high-energy astrophysics, and Ms. Jacob gave a presentation on NASA education resources, at the Norfolk State University (NSU) teacher workshop, ‘‘Topics in Modern Astronomy.’’ NSU is a partner minority university and began a second three-year grant with GSFC in FY04. Ms. Jacob supported the GSFC Education Office in development of an educator workshop for NASA Explorer Schools based on NIGHTGLOW and balloon science. During a month of the TIGER Antarctic balloon campaign, Dr. Christian kept an online journal for the public, answered student questions, and provided photographs for the Website. The Cosmic and Heliospheric Learning Center Website is undergoing a name change to Cosmicopia; the name chosen in an online public contest. Cosmicopia is a tutorial on heliospheric and cosmic ray science with related news and activities; it includes a glossary and history, as well as the continuing ‘‘Ask a Physicist’’ service with hundreds of Q&A provided by ACE and other scientists, including Drs. Christian, Barbier, and de Nolfo.

Dr. Harrus was awarded an Education and Public Outreach proposal in conjunction with an HST proposal (PI. Dr. Ravi Sanskrit). The project, an innovative collaboration between scientists and a professional theater company based in DC, will premiere in Spring 2005.

A project conceived and proposed in collaboration with RIME (Renovation In Music Education) was awarded a two-year IDEAS grant. Dr. Harrus, in collaboration with high-school science teachers Margaret Strohecker (Berwyn Heights), Margaret Pennock and David Wood (Sidwell Friends), is currently working on the science curriculum units parts of the ‘‘Orchestra’s guide to the Universe.’’ The first performance with a professional-level orchestra is scheduled for April 30, 2005.

The E/PO program for the Astro-E2 mission, led by Dr. Lochner, is preparing an education video about the mission, featuring the final development of the X-ray microcalorimeter and the fabrication of X-ray mirrors. A teacher guide is also being prepared to guide teachers in use of the video and to provide further information. The Astro-E2 E/PO team is also sponsoring a student competition for high school students to share in the data from the Xx-ray spectrometer. The competition will be open for entries starting winter 2004. Dr. Lochner has been assisted by Dr. Boyce from the XRS instrument team to produce an E/PO video.

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